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THE ENDURANCE TRAINING EFFECTS OF HIGH – ALTITUDE ALPINISTIC EXPEDITION MAY BE LESS STRONG STIMULUS FOR PERFORMANCE IN HYPOXIA, THAN ACCLIMATIZATION

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Abstract

Objective: To ascertain whether the exercise stimulus during high–altitude alpinistic expedition is enough strong to influence alpinists performance similarly as acclimatization.

Methods: Two groups: 4 alpinists (age: 45 ± 8 yrs; BW: 75 ± 5 kg; BH: 171 ± 20 cm) who reached the summit of the Gasherbrum II (GAS) and 5 alpinists (age: 55 ± 11 yrs; BW: 74 ± 9 kg; BH: 177 ± 7 cm) who reached the summit of the Ama Dablam (AMA), were voluntary participated in the study. They repeated incremental test on the cycle ergometer before and after expeditions in normoxic and hypoxic (FiO_2= 0.18) conditions.

Results: Lactate Threshold (LT) (146 ± 28 W before and 149 ± 13 W after) and Ventilatory Threshold (VT) (144 ± 36 W before and 134 ± 16 W after) remained unchanged on GAS, but increased from 140 ± 14 W before to 164 ± 10 W (P < 0.05) after AMA expedition during testing in normoxic conditions. During exercise at the same reference power limit (RPL) intensity before and after GAS expedition V_E increased from 83 ± 9 to 104 ± 16 l/min (P < 0.01) during normoxic and from 111 ± 13 to 135 ± 12 l/min during hypoxic testing. Differently, V_E did not change in AMA. Acclimatization significantly increased SaO_2 during RPL in GAS expedition (89 ± 1 % before to 92 ± 1 % (P < 0.01) after, but not in AMA.

Conclusions: Results showed a strong acclimatization effect in GAS expedition. The increase of endurance was presented only in less endurance subjects in AMA.

***Key words**: hypoxia, ventilation, SaO_2, acclimatization, endurance*

The main target of the modern high–altitude alpinist expeditions is not anymore reaching the summit, but to select the most difficult climbing direction. Therefore, the extreme climbing and climate conditions should be overcome. For reaching this goal, the acclimatization and endurance performance should be appropriate. Acclimatization seems very important characteristics due to predominance aerobic exercise during mountaineering and climbing at high–altitudes, for several hours daily and for several weeks on the expedition. Subjects who climb to high altitude experience profound physiologic adjustments when exposed to such extreme environmental challenges. One of the earliest responses to hypoxia is an increase in pulmonary ventilation $\dot{V}_E$ [1]. The resting ventilatory response to hypoxia (HVR) is one of the most fascinating characteristics that reveal individual sensitivity response of peripheral chemoreceptors to hypoxia [2,3]. Respiratory centers are activated by reduced partial pressure of oxygen (PO_2). This results in an increase in V_E and a decrease in blood (PCO_2). Consequently, shift in oxyhemoglobin saturation curve to the left indicates that blood becomes more oxygenated at similar PO_2 [4,5]. The decrease in PCO_2 (hypocapnia) also increases blood pH that tends to decrease V_E [1]. Nevertheless, during exercise at altitude and/or hypoxia the V_E increases dramatically [4]. In contrary, the intensity of climbing at high altitude decreases due to reduction of $\dot{V}O_2$max [4]. It is not typically limited by fatigue of leg muscles but, rather, by fatigue of respiratory muscles.

Mountaineering with additional load (backpack) to base camps (usually about 5000 m in Himalaya) represents exercise which at the beginning (low altitude) represents 50–60% of $\dot{V}O_2$max [4,6]. By increasing altitude this relative exercise intensity increases to 90 % VO_2max at altitude of 7000–8000 m due to decreases of $\dot{V}O_2$max because of hypobaric hypoxia [4,6]. As a consequence, the climbing intensity decreases too. Question arises whether such low – intensity training, which is repeated daily during expedition, influence endurance of alpinists. It is difficult to predict significant enhancement of endurance during normoxic conditions, because of low intensity, but this work, which is performed in hypoxic environmental conditions may enhance endurance in hypoxic conditions, where acclimatization take a part. To find possible influences of high–altitude expedition on endurance performance on one side and on acclimatization on the other was the aim of the study. Two different groups

of alpinists on two different expeditions were selected to find possible differences in acclimatization and/or endurance adaptations.

Materials and methods

Four experienced mountain climbers (mean±SD): age 45±8 yrs, body weight (BW) 75±5 kg, body height (HT) 171±9 cm, from Gasherbrum II (8032 m) (GAS), and five veteran alpinists (age 55 ± 11 yrs, BW 74 ± 9 kg, HT 177 ± 7 cm, from Ama Dablam (AMA) (6828 m) expedition volunteered to participate in our study. The study was approved by the National Ethic Medical Committee and all subjects read and signed the consent form prior to any testing.

A week before departure to both expeditions, all subjects completed an initial incremental cycle ergometry test in normobaric hypoxic (FiO_2 = 18%) conditions after a night's sleep in hypoxic conditions. Both, sleeping and testing were administered in a room with controlled environmental conditions (nitrogen house). Two days later, they performed the test in normoxic conditions. The mountain climbing expedition in the ascent phase lasted 1 month. In the first period mountain climbers climbed to a base camps (about 5000 m) over a 7 day period. During the next 3 wks they gradually acclimatized via prepared altitude camps and subsequently reached the summit. The descent phase lasted 10 days and included a few days of trekking in the narrow region. The final 1-2 weeks was spent relaxing with no exercise training being performed until final testing. The testing procedure was repeated using the same procedures as before the high altitude exposure.

Each subject participated in 4 incremental tests on a cycle ergometer. None of the subjects were trained cyclists. The first test was an incremental test on a cycle ergometer (818E Ergomedic, Monark, Sweden) in ambient normobaric hypoxia (HYP) (FiO_2 = 18%). The test was performed following an over-night sleep under the same environmental conditions. The incremental test started at 60 Watts (W) and increased by 40 W every 4 min until voluntary fatigue. The peak power output achieved was used as the reference power limit (RPL) for subsequent tests. The second test was a repeat of the first incremental test to the reference power limit (RPL) reached during HYP testing. However, this test was performed under normoxic conditions (NOR). This test was performed 2 d after the first one and it was preceded by 48-h of habituation to normoxic conditions. The third test was performed 1 mo after subjects reached the summit of Gasherbrum II. This test was a repeat of the first test conducted in hypoxia after a night's sleep in normobaric hypoxia. The fourth test was a repeat of the second test conducted in NOR; this test was performed 2 d after the third test.

During testing, blood lactate concentration ([LA]) was measuring by LP400 laboratory photometer (dr Lange, Berlin) and pulmonary ventilation (V_E) was measured using a Metamax Plus II (Cortex, Leipzig, Germany) metabolic cart. Additionally, the capillary blood gas PO_2 was measured utilizing an ABL 5 analyzer (Radiometer, Copenhagen, Denmark). Capillary blood samples in the amount of 60-80 μl were obtained from hyperemic ear lobe. Arterial blood O_2 saturation (SaO_2) was measured using a TrueSignal pulse-oximeter (Ohmeda, Switzerland).

Statistical analysis

[LA] data from incremental testing protocol were used for estimating Lactate Threshold (LT) by using log-log model [7]. Additionally, the $\dot{V}_E$ data from the same testing protocol were used for estimating Ventilatory Threshold (VT) by v-slope model [8]. The reference power limit intensities (RPL) were used to compare SaO_2 and $\dot{V}_E$ at similar exercise power. Corresponding SaO_2 and $\dot{V}_E$ were further compared. A two way analysis of variance was used for estimating significance between data obtained before and after certain expedition and for comparison values obtained during normoxic and hypoxic environmental conditions. Additionally, the paired *t*-test was applied to determine statistically significant differences of specific interest, using Sigma Plot 11 and Sigma Stat 3 (Systat Sofware, Inc., Erkrath, Germany).

Results

Training effects

These effects were observed during testing in normoxic conditions (NOR) at Lactate Threshold (LT) and Ventilatory Threshold (VT) intensities, determined at incremental test (Table 1) and at RPL intensities (Table 2 and 3). The exercise intensity corresponded to LT (P_{LT}) and VT (P_{VT}) did not changed significantly at GAS. Similarly P_{LT} values remains unchanged but P_{VT} values during NOR testing increased ($P < 0.05$; Table 1) at AMA expedition. During HYP testing P_{VT} did not changed during AMA expedition (Table 1). RPL intensity was reached at 202 ± 29 W in GAS expedition. $V_{E\,RPL}$ increased for about 21 l/min ($P < 0.05$) (Table 2). Parameters HR, and [LA] remained similar. During AMA expedition, RPL remained at 175 ± 12 W (Table 3). Also, HR, [LA] and $\dot{V}_E$ remained unchanged (Table 3).

Combination of training and acclimatization effects

These effects were observed during exercise at LT, VT and RPL intensities in HYP conditions both in GAS and AMA expedition (Table 1, 2 and 3). There were no changes in P_{LT} and PV neither in GAS nor in AMA expedition (Table 1). HR and [LA] didn't show changes at RPL intensity, neither in GAS nor in AMA expedition (Table 2 and 3). $\dot{V}_E$ showed a strong ten-

Table 1. *Exercise intensity (P) determined by Lactate Threshold (LT) and Ventilatory Threshold (VT) during testing in normoxic (NOR) and hypoxic (HIP) conditions in Gasherbrum (GAS) and Ama Dablam alpinist expeditions (AMA). Values are arithmetic means ± SD*

	P_{LT}(W)	P_{VT}(W)
Gasherbrum expedition (GAS)		
PRE – NOR	146 ±28	144± 36
POST – NOR	149 ±13	134 ± 16
PRE – HIP	124 ± 12	132 ± 51
POST – HIP	131 ± 40	129 ± 43
Ama Dablam expedition (AMA)		
PRE – NOR	147 ± 17	140 ± 14
POST – NOR	159 ± 21	164 ± 10 *
PRE – HIP	112 ± 12	118 ± 31
POST – HIP	129 ± 33	127 ± 35

*statistically significant difference when PRE – NOR and POST – NOR. Values are compared ($P < 0.05$).

Table 2. *Measurements achieved at similar absolute reference power limit (RPL) intensity and similar relative individual power limit (R-IPL) intensity during incremental tests before and after GAS expedition. Values are mean ± SD*

	P (W)	HR (min^{-1})	[LA] (mmol/l)	$\dot{V}_E$ (l/min^{-1})	SaO_2 (%)
PRE – NOR	202 ±29	152±19	1.7±0.2	83 ± 9	96 ± 1
POST – NOR	202 ±29	154±15	2.6±1.0	104 ± 16	95 ± 1
PRE – HYP	202 ±29	156±21	3.5±1.3	111 ± 13	89 ± 1
POST - HYP	202 ±29	158±20	2.4±1.1	135 ± 12 *	91 ± 1 *

*significantly different between PRE-HYP and POST - HYP ($P < 0.05$)

Table 3. *Values determined by reference power limit (RPL) before (PRE) and after (POST) Ama Dablam expedition (AMA). Values are presented as arithmetic mean ± SD*

	P (W)	HR (min^{-1})	[LA] (mmol/l)	$\dot{V}_E$ (l/min)	SaO_2 (%)
PRE – NOR	175 ± 12	131 ± 6	2.9 ± 1.0	66 ± 7	97 ± 1
POST – NOR	175 ± 12	133 ± 36	2.2 ± 0.8	65 ± 3	98 ± 1
PRE – HIP	175 ± 12	152 ± 10	6.1 ± 0.5	94 ± 27	84 ± 4
POST - HIP	175 ± 12	153 ± 22	5.4 ± 2.5	104 ± 16	87 ± 5

*statistically significant between PRE – NOR and POST - NOR ($P<0.05$)

dency for increasing at RPL intensity in GAS (Table 2) and a weak tendency for increasing in AMA (Table 3). The SaO_2 increased ($P< 0.05$) after GAS (POST – HYP) in comparison to values obtained before expedition (PRE – HYP) (Table 2). The SaO_2 showed a clear tendency for increasing values, however without significant differences (Table 3).

The adaptations observed at resting

The significant reduction in body weight (BW) from 75 ± 10 kg to 67 ± 9 kg ($P < 0.01$) in GAS expedition was observed. Differently BW was not changed during AMA expedition.

Discussion

The major findings of the study were adaptations, which showed a clear acclimatization effects, but an absent or low enhancement of endurance by high-altitude alpinist expeditions. More precisely, the acclimatization adaptations were more enhanced during Gasherbrum II expedition as a result of more dramatic environmental stress and alpinist exercise circumstances. Differently, the training effects were obtained in AMA when subjects performed lower exercise intensity as during GAS, but have lower pre – expedition endurance performance, estimated by reference power limit (RPL).

Acclimatization effect was ascertained as a difference of arterial oxygen saturation (SaO_2) during hypoxic exercise before and after both alpinist expeditions. The phenomenon was larger after Gasherbrum II expedition due to a larger SaO_2 increase at similar RPL intensity in hypoxic conditions (Table 2). During similar RPL intensity a clear tendency to higher SaO_2 were found in AMA expedition (Table 3).

The typical acclimatization effect is also increase of $\dot{V}_E$ [1,3,9]. The regulation of $\dot{V}_E$ during rest in normoxia is rather complex and not yet completely understood [9]. Much of $\dot{V}_E$ regulation is based on chemoreflex drive from peripheral PO_2 and PCO_2 and presence of chemoreceptors in the aortic arch and carotid arteries [2]. Additional influences on respiratory centers come from central receptors [9]. Influence from both chemoreceptors and central receptors may stimulate respiratory centers differently, dependent on similarities or differences in chemical composition of blood and cerebrospinal fluid (CSF) [9,10]. Exercise is a very potent respiratory stimulus, especially at altitude [1,4]. Afferent sensory reflexes stimulate respiratory centers by activating peripheral muscle mechanoreceptors and chemoreceptors [4]. Elevated ventilation during exercise in general, and especially in hypoxia, is therefore an integrated influence of all three above mentioned sources of stimulus and modified by individual sensitivity of receptors [3]. It occurs very rapidly during hypoxic exposure and persisted throughout the whole period of expedition. Both, the exercise and hypoxia influence ventilation in a manner that causes low intensity exercise to become more intense due to a greater effort of respiratory muscles [10]. Respiratory work becomes important in determining the intensity of climbing at high altitude. Therefore, climbing per se, at low intensity exercise may not represent adequate training stimulus for adaptations of respiratory and leg skeletal muscles. However, with the addition of hypoxia, it represents a powerful stimulus that can increase the activity of enzymes of aerobic processes and myoglobin content in both muscles [11,12]. The maximal effort of respiratory muscles that occurs during hypoxia at high altitude can increase the demand and thus subjects' performance.

Reduction in BW occurs dramatically during high altitude exposure due to several factors as reported by Boyer and Blume [13], and Bales et al. [14]. Acute dehydration occurs in the first phase because of loss of appetite and as a consequence there is decrease in food intake and an increase in exercise [13]. Additionally, interstitial malabsorption of carbohydrates and fats lead to enhanced catabolism [13]. At extreme altitude, significant muscle wasting occurs irrespective of body composition [14]. Smaller muscle mass may provide an advantage via an increase in capillary density and mitochondrial density associated with smaller muscle fibers [12]. As a consequence, fat and lean mass are reduced. Nitrogen balance shows that nitrogen excretion increases due to increased oxidation of glycine as a function of altitude exposure [15].

Endurance performance was not enhanced during Gasherbrum II, but increased during Ama Dablam expedition. Therefore, climbing for several hours per day, for a month, which was more difficult in GAS expedition did not represent adequate stimulus for enhancement of endurance performance. These results did not surprise. Even the best high-altitude alpinists reached maximal aerobic power at about 50 ml/kg·min^{-1} [3,4]. Alpinists in GAS expedition reached $\dot{V}O_2$ peak about 50 ml/kg·min^{-1} and in AMA expedition 46 ml/kg·min^{-1}. The reasons for such low aerobic power and an absent of effects on endurance performance may related to low mechanical exercise intensity during climbing because of hypoxia [4]. However, the less endurance subjects according to reached RPL intensity in AMA expedition, probably got a higher dose of training stimulus relative to their endurance performance, which might influenced on enhancement of endurance.

In conclusion. In contrast to a clear acclimatization effect of high–altitude alpinistic expeditions, the endurance training effects of such activity was smaller or even negligible. Therefore, it seems less strong for endurance performance enhancement than that of acclimatization.

Declaration of interest

The authors report no conflicts of interest.

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